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Lactic Acid—Versatile Intermediate for the Chemical Industry

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The value of a chemical intermediate may be measured by (a) the nature, abundance and cost of its precursors or raw materials, and (b) the number, desirability, usefulness and diversity of the products that can be made from it. Lactic acid, a three-carbon compound having two functional groups, enjoys a high rating on both points. It can be made efficiently from several normally low-cost, abundant and, in some instances, reproducible, raw materials, including starches, wood, whey, sucrose, invert sugar, molasses, sulfite waste liquor (50), coal, petroleum and natural gas. At present lactic acid is manufactured (18,61-63,95-97) both from agricultural raw materials (starch hydrolyzates and whey) by fermentation and synthetically (as ethyl lactate) from acetaldehyde, a chemical that can be made economically from petroleum, natural gas, or coal. Lactic acid, easily meeting the first requirement of a satisfactory intermediate, is even more versatile with respect to the second requirement, that is, the number, diversity and usefulness of the materials that can be made from it. Lactic acid, by virtue of its two reactive functional groups, enters into many reactions and can be transformed into many products. It is with these reactions and products, including their actual or potential usefulness, that the present paper is primarily concerned.

Manufacture and Cost

Since the position and merit of a chemical intermediate are invariably linked with the efficiency and cost of its manufacture, these points and the present lactic acid industry (46,61,81) in the United States are discussed briefly below.[1]

[1] References 61 and 81 should be consulted for more detailed information on the manufacture, recovery methods, commercial grades and present uses of lactic acid.

Lactic acid made by fermentation is transformed commercially into the methyl and n-butyl esters. Ethyl lactate is made synthetically, the raw materials being acetaldehyde, hydrogen cyanide and ethanol. Although lactic acid can be made in moderately high yields by treating sucrose with calcium hydroxide (41), apparently all the lactic acid of commerce is made by fermentation. The theoretical yield of lactic acid is 100% of the weight of fermentable hexose sugar, but the yield actually obtained commercially ranges from approximately 80 to 95%.

The manufacture and chief uses for lactic acid were developed by Americans, the industry being well maintained in the United States before the manufacture of lactic acid was undertaken elsewhere (81,91). The first lactic acid factory was established in Littleton, Massachusetts, in 1881 by Charles E. Avery (81,91). Production in the United States increased from about 10,000 lbs. in 1894 to about 400,000 lbs. in 1897, and to over 1,000,000 lbs. (calculated as 100% acid) in 1917, when there were six manufacturers (62,81). As is shown below, the production of lactic acid has increased greatly during the last few years (81).

Table I. PRODUCTION OF LACTIC ACID (100% BASIS) IN THE UNITED STATES[a, b]

Year	Technical, lbs.	Edible, lbs.	Total, lbs.
1939	1,530,456	1,609,094	3,139,550
1940	1,671,237	1,492,301	3,163,538
1941	2,646,000	2,334,000	4,980,000
1942	2,931,000	3,124,000	6,055,000
1943	3,242,000	4,243,000	7,485,000
1944	4,458,000	4,161,000	8,619,000
1945	3,467,000	4,672,000	8,139,000

[a] U.S. Tariff Commission Reports (90).
[b] Production of sodium lactate: 324,000 lbs. in 1944 and 129,000 lbs. in 1945.

The data given below show that lactic acid is relatively inexpensive in the crude grades but moderately expensive as the refined material. Although the refined grades are needed for some uses, the crude, technical acid can be easily esterified and refined (24-6,28,61).

Table II. PRICES OF VARIOUS GRADES OF LACTIC ACID[a] IN 1947

Grade	Concentration, %	Cents per Pound	
		As Sold	100% basis
Edible	50	14.5	29
"	80	24.25	30.3
Plastics	50	17.75	35.5
"	80	31.75	39.7
Technical	22	4.40	20
"	44	8.15	18.5
U.S.P. XII	80	54.0	67.5
U.S.P. VIII	70	52.0	74.3

[a] Oil, Paint and Drug Reporter, 152(1) 9 (July 7, 1947).

Lactic acid and certain of its esters compare favorably in price with some of the relatively inexpensive organic acids and esters (Table III).

Table III. PRICES OF SEVERAL COMMERCIAL ACIDS AND ESTERS[a]

	Cents Per Pound			
	Acid	Methyl Ester	Ethyl Ester	n-Butyl Ester
Acetic	7.62	10.5	21.5	16.5
Propionic	14	-	-	-
Butyric	32	-	-	-
Lauric	29.5	-	-	42
Stearic	27.5	-	-	45
Benzoic	43	45	50	-
Phthalic anhydride	14.5	21	28	30.5
Glycolic[b]	12 (100% basis)	-	-	-
Lactic[c]	18.5 (100% basis)	31[d]	38.5	39
Citric	22	-	-	41
Salicylic	31	40	-	-
Oleic	20	-	47	35
Oxalic	13	-	34	-

[a] Oil, Paint and Drug Reporter, 152 (1) (July 7, 1947).
[b] Sold in 70% concentration.
[c] Sold in 44% concentration.
[d] Private communication from the manufacturer.

According to Groggins (37), the calculated materials cost of manufacturing lactic acid from sugar priced at 2 and 3 cents per pound should be 4.04 and 5.18 cents per pound, respectively. On this basis, when fermentable sugar is available at 1 and 5 cents, the calculated materials costs of lactic acid would be 2.91 and 7.45 cents per pound, respectively, the cost of lactic acid being related to the cost of sugar as shown below (cents per pound):

Materials cost of lactic acid = 1.136 x (cost of sugar) + 1.77.

It should be emphasized that the data given above are concerned only with the cost of the raw materials.

Since the actual selling price (Table II) of lactic acid is considerably higher than the materials cost suggested above, probably it will be possible to lower the price of lactic acid appreciably by increasing the scale of production and developing improved manufacturing methods. Possible improvements in lactic acid manufacture worthy of investigation include neutralization of lactic acid during the fermentation with ammonium hydroxide (45) and subsequent recycling of ammonia (or sale of byproduct ammonium sulfate), neutralization of calcium lactate with carbon dioxide under pressure and filtration of calcium carbonate, and recovery of lactic acid and calcium hydroxide from fermentation liquor by electrodialysis (15). Any improvement in production or recovery methods and concomitant reduction of costs obviously should greatly enhance the position of lactic acid as an industrial raw material.

Although some lactic acid is converted into plastics, solvents and certain other chemical products, most of it is used as such for deliming and plumping hides and as an acidulant for foods and beverages (61,81).

Solvents

Although the boiling points of lactic acid derivatives are so high that their use in the large-volume volatile solvent industry is precluded, lactic esters and ethers have high solvent power, and their boiling points and evaporation rates are suitable for a number of important potential uses, including the preparation of specialty lacquers, varnishes, inks, stencil pastes and organosols. The high solvent power of the lactic acid derivatives is due to the presence of two or three of the following groups: Alcoholic hydroxyl, ester and ether. Examples of lactic acid derivatives that are of interest as solvents are listed in Table IV; three of these (methyl, ethyl and n-butyl lactates) are commercially available and are now used as solvents (17).

Table IV. LACTIC ACID DERIVATIVES AS SOLVENTS

Ester	B.p., °C. (mm.)	$d_{t'}^{t}$	Solubility in water, g./100 ml.[a]	Reference
Methyl lactate	144.8 (760)	1.0898^{19}	Miscible	82
Ethyl "	154.5 (760)	1.0308^{19}	"	82
n-Propyl "	171.7 (760)	0.996_{20}^{20}	"	82,44
i- " "	166-8 (760)	0.998_{20}^{20}	"	82
n-Butyl "	185 (760)	0.973_{20}^{20}	4.36	82
i- " "	182.2 (760)	0.971_{20}^{20}	-	82,44
s- " "	180 (760)	0.974_{20}^{20}	-	82
1-Amyl "	202.4 (760)			44
beta-Ethoxyethyl lactate	86-7 (5)	1.0591_{4}^{20}	-	22
Methyl lactate acetate	171.5 (760)	1.088_{4}^{20}	8.12	11,82
Ethyl " "	177 (733)	1.0458^{17}	3.37	82
n-Propyl " "	195-6 (766)	1.0163_{25}^{25}	0.99	82
n-Butyl " "	213-4 (767)	1.0001_{4}^{20}	0.32	82
i- " " "	205 (763)	0.9952_{25}^{25}	-	82
Methyl lactate propionate	65 (6.8)	1.0540_{4}^{20}	2.2	a
beta-Ethoxyethyl lactate acetate	105-6 (6)	1.0619_{4}^{20}		22
Methyl alpha-methoxypropionate	45 (22)	$.9967_{4}^{20}$	-	64
Ethyl "	46 (12)	$.9551_{4}^{20}$	-	64
Ethyl alpha-ethoxypropionate	153-5 (755)	0.9446_{4}^{20}	-	47
Methyl alpha-butoxypropionate	168-9 (750)	0.9346_{4}^{20}	-	42
n-Butyl "	219-21 (750)	0.9058_{4}^{20}	-	42

[a] Unpublished data of the Eastern Regional Research Laboratory.

Plasticizers

Lactic acid can be transformed into numerous high-boiling derivatives that potentially are of value as plasticizers. Although the use of certain lactic acid derivatives for this purpose has been suggested (8, 9, 10, 19-21, 23, 38, 71-3) apparently lactic acid has not been used to an appreciable extent as a raw material for making plasticizers. The following are mentioned as examples of products that might be expected to function satisfactorily as plasticizers: Laurate of butyl lactate (20), ethyl carbonate of 2-butoxyethyl lactate (73), bis-(ethyl lactate) phthalate,[2] dipelargonate of diethylene glycol dilactate,[2] dipropionate of 1,5-pentanediol dilactate,[2] tetrapropionate of pentaerythritol tetralactate,[2] propionate of octyl polylactate (23), propionate of 2-ethylhexyl polylactate (23), diglycol carbonate of butyl lactate (71), and propionate of diethylene glycol monolactate monolaurate.[2]

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[2] Unpublished work of the Eastern Regional Research Laboratory.

Favorable preliminary results have been obtained in studying these and many similar products at the Eastern Regional Research Laboratory.

Plasticized vinyl chloride compositions were given most attention in this study, but other important resins also were investigated. The performance of some of the lactic acid plasticizers is compared with that of octyl phthalate in Table V. As judged by modulus at 100% elongation and brittle point, the efficiency of some of the plasticizers is comparable or superior to that of the control.

Table V. LACTIC ACID DERIVATIVES AS PLASTICIZERS FOR VINYL CHLORIDE COPOLYMER[a, b]

Plasticizer	Tensile Strength, p.s.i.	Modulus, 100%	Elongation, %	Brittle Point, °C.
(2-Ethylhexyl phthalate) (control)	(3150)	(1500)	(320)	(-32)
Laurate of 2-butoxyethyl lactate	2350	1310	240	-44
" " n-butyl polylactate[c]	3110	1780	290	-30
Di-2-ethylhexoate of diethylene glycol dilactate[d]	3290	1480	360	-31
Adipate of n-butyl lactate[e]	3150	1110	340	-30
Diglycol carbonate of n-octyl lactate[f]	3440	1590	320	-17

[a] References 20, 23, 73.

[b] Copolymer of 95% vinyl chloride-5% vinyl acetate, 63.5 parts; basic lead carbonate, 1 part; stearic acid, 0.5 part; and plasticizer, 35 parts.

[c] $CH_3(CH_2)_{10}COOCH(CH_3)COOCH(CH_3)COOCH(CH_3)COO(CH_2)_4H$

[d] $(CH_3(CH_2)_3CH(C_2H_5)COOCH(CH_3)COOCH_2CH_2-)_2O$

[e] $(-CH_2CH_2COOCH(CH_3)COO(CH_2)_4H)_2$

[f] $O(CH_2CH_2OCOOCH(CH_3)COO(CH_2)_8H)_2$

It is possible that some of the lactic acid derivatives prepared for study as plasticizers will be found useful as lubricating oil additives, special lubricants and hydraulic fluids.

Allyl Monomers and Polymers

Although this class of materials might be limited to compounds having two or more allyl groups, for purposes of convenience a broader classification is used, and lactic acid derivatives having two or more polymerizable groups roughly similar to the allyl group are included. Compounds of this general type that should be capable of yielding insoluble, infusible and cross-linked "allyl" resins (43) are illustrated by the formulas given below, where R and R' are allyl, methallyl, crotyl, cinnamyl, methyl vinyl carbinyl, dicyclopentadienyl (2,5) and similar groups.

$$ROCH(CH_3)COOR'$$
$$ROCOOCH(CH_3)COOR'$$
$$CO(OCH(CH_3)COOR)_2$$
$$O(CH(CH_3)COOR)_2$$
$$(ROCOOCH(CH_3)COOCH_2-)_2$$

Derivatives of lactic acid (such as the acrylates, methacrylates, vinyl esters and ethers and 2-chloroallyl esters) that polymerize or copolymerize readily to yield thermoplastic polymers of high molecular weight are discussed elsewhere.

The allyl monomers thus far prepared from lactic acid polymerize when heated in the presence of benzoyl peroxide yielding hard, transparent, insoluble, infusible and substantially colorless resins. Allyl lactate ($HOCH(CH_3)COOCH_2CH{:}CH_2$), which can be made easily in high yields (69), is an excellent starting point for making polymerizable esters of the allyl type. The anhydrides or acid chlorides of various unsaturated or polybasic acids, such as allylcarbonic, crotonic, maleic, fumaric, allyloxypropionic, oleic, succinic, carbonic, phthalic and adipic, can be used to prepare esters of allyl lactate that are known or would be expected to yield three-dimensional resins on polymerization.

Muskat and Strain (57,58) claim that the following allyl derivatives of lactic acid can be used to prepare useful laminates, coatings and optical plastics:

$$CH_2{:}CHCH_2OCOOCH(CH_3)COOCH_2CH{:}CH_2$$
$$CO(OCH(CH_3)COOCH_2CH{:}CH_2)_2$$

The properties of some of these materials (Table VI) show that polymeric bis-(allyl lactate) carbonate can be compared favorably with some of the commercial allyl resins.

Polymer	Impact Strength[b] ft. lbs./in.	Abrasion Resistance[c]	Flexural Strength, p.s.i.	Acetone Absorption, % (7 days at 25°C.)	Heat Distortion, °C.	Distortion at 130°C., mils[d]	Polymerization Speed
Allymer CR39[e]	2.1	30-35	9,500	0.4	61	40	Typical
bis-(Allyl lactate) carbonate[f]	1.03	8	13,200	-	116	18	"
	1.2	10	13,200	1.0	113	21	"
Allyl phthalate	0.85	2.5-4	12,000	9.9	97	36	Slow

[a] Data kindly supplied by Franklin Strain and Alphonse Pechukas, Columbia Chemical Div., Pittsburgh Plate Glass Company.
[b] Unnotched Izod.
[c] Taber Times methacrylate.
[d] Ease of forming is proportional to this value.
[e] Allyl diglycol carbonate: $O(CH_2CH_2OCOOCH_2CH:CH_2)_2$
[f] Monomer, having the structure $CO(OCH(CH_3)COOCH_2CH:CH_2)_2$, prepared by the interaction of phosgene and allyl lactate.

A polymerizable derivative, $C_{10}H_{13}OCH(CH_3)COOC_{10}H_{13}$, has been obtained by the reaction of lactic acid with dicyclopentadiene in the presence of acidic catalysts (2,5). According to Bruson (2,5), this compound polymerizes readily, yielding a hard, flexible, tough, insoluble and infusible product.

The maleate of allyl lactate has been used to prepare cross-linked or vulcanizable copolymers (30).

Alkyd Resins

Having both hydroxyl and carboxyl groups, lactic acid can be readily self-esterified or polymerized (26). The simple polymers thus far prepared, however, have had relatively low molecular weights; they apparently have little value as such for resin applications. According to reports from the Bureau of Dairy Industry (93,94), insoluble and durable coatings can be made by applying mixtures of polylactic acid and certain other materials to metal objects and baking at relatively high temperature.

Stearn, Makower and Groggins (84) have made three-component alkyd resins by the two operations outlined below:

A. Glycerol + 2 lactic acid ⟶

$$\begin{array}{l} CH_2OCOCH(CH_3)OH \\ | \\ CHOH \\ | \\ CH_2OCOCH(CH_3)OH \end{array}$$

Glyceryl dilactate

B. Glyceryl dilactate + dibasic acids ⟶ alkyd resins

Methyl lactate can be used instead of lactic acid to make the dilactate. Several different alkyd resins were made by treating the glyceryl dilactate (which has as many hydroxyl groups as glycerol) with phthalic, sebacic, azelaic and maleic acids.

Although several investigators (26,36,84) have prepared various types of alkyd resins (51) from lactic acid, this promising field has received relatively little attention, and the products have not been adequately evaluated.

Acrylic Esters and Resins

In 1935 Burns, Jones and Ritchie (6) described the conversion of lactic acid into the methyl, n-butyl and benzyl esters of acrylic acid. Their method of preparing acrylic esters has been studied extensively in the Eastern Regional Research Laboratory, where it was demonstrated that high yields can be obtained in each of the three required steps (25,28, 65):

Polymer	Impact Strength[b] ft. lbs./ in.	Abrasion Resistance[c]	Flexural Strength, p.s.i.	Acetone Absorption, % (7 days at 25°C.)	Heat Distortion, °C.	Distortion at 130°C., mils[d]	Polymerization Speed
Allymer CR39[e]	2.1	30-35	9,500	0.4	61	40	Typical
bis-(Allyl lactate) carbonate[f]	1.03	8	13,200	-	116	18	"
	1.2	10	13,200	1.0	113	21	"
Allyl phthalate	0.85	2.5-4	12,000	9.9	97	36	Slow

[a] Data kindly supplied by Franklin Strain and Alphonse Pechukas, Columbia Chemical Div., Pittsburgh Plate Glass Company.

[b] Unnotched Izod.

[c] Taber Times methacrylate.

[d] Ease of forming is proportional to this value.

[e] Allyl diglycol carbonate: $O(CH_2CH_2OCOOCH_2CH:CH_2)_2$

[f] Monomer, having the structure $CO(OCH(CH_3)COOCH_2CH:CH_2)_2$, prepared by the interaction of phosgene and allyl lactate.

$$\underset{\text{(Crude lactic acid)}}{HOCH(CH_3)COOH} + CH_3OH \longrightarrow \underset{\text{I (90\%)}}{HOCH(CH_3)COOCH_3}$$

$$\text{I + acetic anhydride or ketene} \longrightarrow \underset{\text{II (97\%)}}{CH_3COOCH(CH_3)COOCH_3}$$

$$\text{II} \xrightarrow[\text{550°C.)}]{\text{(Pyrolysis at}} \underset{(90\%)}{CH_2{:}CHCOOCH_3} + CH_3COOH$$

It has also been shown that methyl acetoxypropionate (II), the intermediate used in preparing methyl acrylate, can be prepared in satisfactory yield with acetic acid as the acetylating agent (24) in place of the anhydride or ketene.

This general method gave low yields of ethyl, butyl and similar acrylates (75), and hence it is not suitable for preparing the higher alkyl acrylates. The pyrolysis method, however, can be used to prepare certain acrylates in moderate or high yields. Some of the results obtained by pyrolyzing various lactate acetates ($CH_3COOCH(CH_3)COOR$) are given in Table VII.

Table VII. PYROLYSIS OF LACTATE ACETATES ($CH_3COOCH(CH_3)COOR$)[a]

Lactate Acetate	Yield of corresponding acrylic ester, %[b]	Reference
Methyl	90	65
Ethyl	33	75
Isobutyl	40	75
Benzyl	74	6
Tetrahydrofurfuryl	70-79	22
Allyl	43	31, 78
Methallyl	41	31, 78
2-Methoxyethyl	31	22
2-Ethoxyethyl	37	22
2-Chloroethyl	51	75
Phenyl	80	29
o-Tolyl	75	29
$-OCH_2COOCH_3$	58	27

[a] Vapors of the lactate acetate were passed through a Pyrex-glass tube heated at about 550° C.

[b] Based on the lactate acetate decomposed.

The data on yields in Table VII show conclusively that the pyrolysis method is unsuitable for making many acrylic esters, including the important ethyl and butyl esters. The higher alkyl acrylates, however, can be made by alcoholysis of the lower acrylic esters. For example, methyl acrylate, which is obtained in 90% yield by the pyrolysis of methyl lactate acetate, can be used to prepare many of the higher acrylic esters in excellent yields (74, 76, 77):

$$CH_2{:}CHCOOCH_3 + ROH \xrightarrow[\text{or basic catalyst)}]{\text{(Acidic}} CH_2{:}CHCOOR + CH_3OH$$

Dry acrylic acid can be made conveniently by the acidolysis of methyl acrylate with formic acid or by the pyrolysis of ethyl acrylate (70).

The available information on making methyl acrylate from lactic acid is not adequate for calculating total costs. It has been estimated, however, that the materials cost (which depends primarily upon the cost of lactic acid) should be between 15 and 20 cents per pound when fermentable carbohydrates are available at about 3 cents per pound.

Although the estimated materials cost seems reasonably low in comparison with the selling price of methyl acrylate (approximately 58 cents per pound), it does not necessarily follow that the pyrolysis preparation will be able to compete economically with the methods now being investigated in industrial laboratories. It has been reported, for example, that the Reppe process (7,48) of making acrylic esters from acetylene, carbon monoxide and alcohols is advantageous economically. It is impossible at present to predict either the extent to which the various competing methods can be improved or the outcome of the current contest to make acrylic esters at low cost.

In view of their usefulness for several purposes, including the preparation of coatings (59), elastomers (30,52,53), latices (54,56), plasticizers, adhesives, miscellaneous copolymers (59) and chemical intermediates (70,72), the acrylic esters comprise an important potential outlet for lactic acid.

Acrylamides

Amides of acrylic acid, which polymerize readily, can be made from lactic acid by a method (67,68) similar to that discovered by Burns, Jones and Ritchie (6) for preparing acrylic esters. The preparation of N,N-dimethylacrylamide is outlined below as an example of the method:

$$HOCH(CH_3)COOCH_3 + HN(CH_3)_2 \longrightarrow \underset{\text{I}}{HOCH(CH_3)CON(CH_3)_2}$$

$$\text{I} + \text{Acetic anhydride} \longrightarrow \underset{\text{II}}{CH_3COOCH(CH_3)CON(CH_3)_2}$$

$$\text{II} \xrightarrow[\text{about } 550^\circ\text{C.)}]{\text{(Pyrolysis at}} CH_2{:}CHCON(CH_3)_2 + CH_3COOH$$

The pyrolysis method has not been studied thoroughly, but it has been shown that this method gives high yields of N,N-dimethyl- and N,N-diethylacrylamides.

The polymer of dimethylacrylamide is hard, soluble in water, and insoluble in hydrocarbons (67). Its aqueous solutions are viscous. As would be expected, the higher N-alkyl acrylamides are less soluble in water but more soluble in hydrocarbons. The N-substituted acrylamides, a potentially important class of monomers, can be prepared also from acetylene, carbon monoxide and amines (7,48).

Some of the acrylamides are similar to acrylonitrile and acrylic esters also in being able to react with alcohols, glycols and certain other compounds having active hydrogen. Alcohols, starch and cellulose, for example, react with acrylamide, yielding ether derivatives of beta-hydroxypropionamide, $ROCH_2CH_2CONH_2$ (3,4).

Acrylates and Methacrylates of Lactic Esters

New resin intermediates have been prepared (70) by treating lactic esters with acrylyl chloride or with methacrylic anhydride:

$$CH_2{:}CHCOCl \quad + \quad HOCH(CH_3)COOR \longrightarrow CH_2{:}CHCOOCH(CH_3)COOR$$

$$(CH_2{:}C(CH3)CO)_2O \quad + \quad HOCH(CH_3)COOR \longrightarrow CH_2{:}C(CH_3)COOCH(CH_3)COOR$$

The methacrylates of alkyl lactates have been prepared also by pyrolyzing the corresponding acetoxyisobutyrates (27):

$$CH_3COOC(CH_3)_2COOCH(CH_3)COOR \longrightarrow CH_3COOH \quad + \quad CH_2{:}C(CH_3)COOCH(CH_3)COOR$$

It has been shown that the acrylates and methacrylates polymerize readily, producing both flexible and hard polymers. These polymers differ from the usual acrylic and methacrylic polymers in that they contain two ester groups in each monomer segment, one of which is more reactive than the ester groups in the simple alkyl acrylates and methacrylates.

The additional ester group provided by the lactic acid segment might be advantageous for modifying the compatibility and solubility characteristics of the polymer or in cross-linking reactions facilitated by the presence of relatively reactive ester groups.

The acrylates and methacrylates of lactic esters should become more attractive economically if reagents such as acrylyl chloride and methacrylic anhydride become available at low cost or if inexpensive preparative methods, such as that suggested below, are found:

$$\text{Acetylene} + CO \quad + \quad HOCH(CH_3)COOR \xrightarrow{\text{(Catalyst)}} CH_2{:}CHCOOCH(CH_3)COOR$$

The maleates, fumarates, and itaconates of alkyl lactates also should be suitable for preparing polymers and copolymers.

Vinyl Derivatives

Vinyl lactate, an ester structurally similar to vinyl acetate, should be useful as a monomer and as an intermediate in preparing numerous other polymerizable materials.

Although vinyl lactate has been mentioned briefly (16,88), its polymers and copolymers have been given little attention. Vinyl lactate is one of the few known monomers that can be used to introduce directly an hydroxyl group into copolymers. By acylation of vinyl lactate, it should be possible to prepare many polymerizable vinyl esters having the formula: $RCOOCH(CH_3)COOCH{:}CH_2$.

Although the vinyl ethers[3] and amides listed below have received little or no attention, it would be expected that these compounds would polymerize and copolymerize readily. Moreover, some of the resulting polymers should be water soluble.

$$CH_2{:}CHOCH(CH_3)COOR$$

$$CH_2{:}CHOCH(CH_3)CON(R)_2$$

$$ROCH(CH_3)CON(R)CH{:}CH_2$$

$$CH_2{:}CHOCH(CH_3)CON(CH_3)CH{:}CH_2$$

$$HOCH(CH_3)CONHCH_2CH_2OCH{:}CH_2$$

Lactamides

Methyl lactate and similar lactic esters are more reactive with ammonia and amines (66) than are simple, unsubstituted esters such as methyl acetate and ethyl benzoate. As the result of this reactivity of lactic esters with amines, many lactamides can be made readily from methyl or ethyl lactate and certain commercially available amines. The properties of the lactamides vary with the amine used in the preparation. The amides of low molecular weight, such as N-ethyllactamide are water-soluble, whereas the higher lactamides are water insoluble.

$$HOCH(CH_3)COOCH_3 + RNH_2 \longrightarrow HOCH(CH_3)CONHR + CH_3OH$$

Although secondary amines as a class are less reactive with methyl lactate than are primary amines, certain types of secondary amines can be used to prepare lactamides, $HOCH(CH_3)CONRR$, having two substituents on the nitrogen atom (66).

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[3] Coffman and coworkers (12,13) have described the monomeric and polymeric forms of the vinyl ethers of alkyl glycolates ($CH_2{:}CHOCH_2COOR$).

When simple alkyl amines react with methyl lactate, the resulting lactamides have two functional groups. When amines containing an additional functional group are used, the resulting lactamides have three functional groups. For example, the lactamide obtained from ethanolamine ($HOCH_2CH_2NH_2$) has two hydroxyl groups and one amide group:

$$HOCH(CH_3)CONHCH_2CH_2OH$$

This compound might be useful as a high-boiling water-soluble plasticizer or humectant and as an intermediate in preparing esters, ethers and alkyd resins.

An unsaturated lactamide, $HOCH(CH_3)CONHCH_2CH{:}CH_2$, has been made (66) from methyl lactate and allyl amine. Presumably this unsaturated amide, in reality an unsaturated alcohol, can be used as an intermediate in preparing products of industrial value. It has been reported that a useful surface-active agent, $CH_3(CH_2)_{11}NHCOCH(CH_3)OSO_3Na$, can be made from N-dodecyllactamide. Tests conducted by the Bureau of Entomology and Plant Quarantine indicate that N-n-butyl- and N-n-amyl-lactamides are effective mosquito repellents.

Insect Repellents

The lactic acid derivatives prepared in the Eastern Regional Research Laboratory were submitted to the Bureau of Entomology and Plant Quarantine for evaluation as pesticides and insect repellents. The several derivatives having considerable efficiency as mosquito repellents are shown in Table VIII. Although these compounds[4] apparently are somewhat

[4] These compounds have not been adequately tested for toxicity and physiological properties, and they should not be used as repellents until it has been demonstrated that they are harmless to the host.

less effective than certain other recommended repellents, they are of interest because of their structural simplicity, ease of production or low cost. Granett (35) has obtained a patent on mosquito-repelling compositions containing 2-ethoxyethyl lactate.

Table VIII. LACTIC ACID DERIVATIVES AS MOSQUITO REPELLENTS[a]

	Effective Time, min.	
	A. quadri-maculatus	*Aedes aegypti*
(Dimethyl phthalate-control)	(200)	(180)
(Ethyl hexanediol-control)	(60)	(360)
(Indalone-control)	(15)	(180)
n-Octyl lactate	68	164
Tetrahydrofurfuryl alpha-acetoxypropionate	20	173
bis-(Methallyl lactate) maleate	27	138
2-Butoxyethyl lactate	78	199
2-Butoxyethoxyethyl lactate	20	228
bis-(i-Butyl lactate) maleate	46	170
Ethylene glycol monolactate	-	158
Ethyl alpha-propionoxypropionate	-	159
n-Tetradecyl lactate	-	144
i-Propyl carbonate of methyl lactate	90	92
N-n-Butyllactamide	-	145
N-n-Amyllactamide	-	265

[a] Data kindly supplied by the Bureau of Entomology and Plant Quarantine, U.S. Department of Agriculture.

Miscellaneous

Lactic esters have been transformed by chemical oxidation (80,83), catalytic vapor-phase oxidation (49) and dehydrogenation (40) into alkyl pyruvates, $CH_3COCOOR$. Having the carbonyl, ester and active methyl functional groups, the pyruvates, are capable of entering into many reactions. When made available at reasonable cost, pyruvic acid derivatives, should become important industrial chemicals.

Several dibasic ether acid derivatives have been prepared from lactic acid by the method shown below (34):

$$NaOCH(CH_3)COOC_2H_5 + ClCH_2COOC_2H_5 \longrightarrow O\begin{cases} CH_2COOC_2H_5 \\ CH(CH_3)COOC_2H_5 \end{cases}$$

Such dibasic acid derivatives should be useful in preparing plasticizers, alkyd resins, and other useful products. Chloroformates ($ROCOCH(CH_3)OCOCl$) that should be useful as chemical intermediates have been made by treating alkyl lactates with phosgene (86).

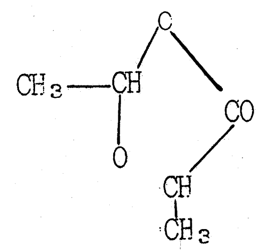
Propylene glycol (1) and propanolamine (14) have been made by hydrogenating lactic esters and lactamide, respectively. Both these chemicals ($CH_3CHOHCH_2OH$ and $CH_3CHOHCH_2NH_2$) are of industrial value.

Hagemeyer (39) prepared acrylonitrile, an important resin and elastomer intermediate, by passing acetic anhydride--lactamide (or ammonium lactate) mixtures through a preheater and pyrolysis chamber.

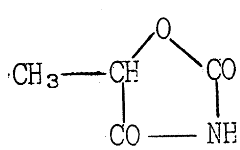
Lactic acid derivatives can be converted into esters of inorganic acids by treatment with phosphorous oxychloride (33), thionyl chloride (32, 79), phosgene (79), and boric anhydride (87).

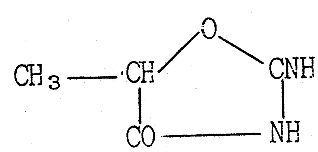
It has been demonstrated that 2-chloroallyl lactate, which can be prepared readily, is capable of copolymerization with certain other monomers, including acrylic esters. Copolymers of 2-chloroallyl lactate can be cured or vulcanized (55).

Acetaldehyde and certain other carbonyl compounds react with lactic acid to form heterocyclic derivatives (60, 98). The product made from acetaldehyde has the structure:



Other cyclic products can be made by treating lactic esters with urea (85), lactamide with methyl carbonate (92), and ethyl lactate with guanidine (89). The 5-methyl-2,4-oxazolidine-dione obtained from the first two reactions and the 5-methyl-2-imino-4-keto-oxazolidine obtained from the guanidine reaction are shown below:





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Summary

It has been shown that lactic acid, a chemical capable of entering into many types of chemical transformations, can serve as a raw material in making various resins, solvents, plasticizers and other important industrial products. Like ethylene, acetylene or benzene,--lactic acid is versatile enough, chemically, to be used as the cornerstone of an organic chemical industry. Although lactic acid probably could be used on an expanded scale at present price levels, its full potentialities as an intermediate cannot be realized until (a) its price is lowered by virtue of improved methods and large-scale manufacture and (b) further work is done on the production and evaluation of products derived from it. It is believed that some of these objectives will be attained and that the industrial importance and usefulness of lactic acid will continue to increase.

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